Ultra-Light, inTegrated, Reliable, Aviation-class, Co-Optimized Motor & Power converter with Advanced Cooling Technology (ULTRA-COMPACT)

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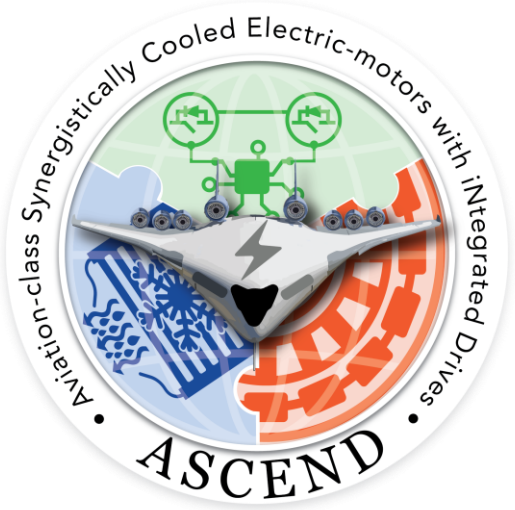

Project Vision: The ULTRA-COMPACT electric propulsion system leverages:

1. A high-speed permanent magnet machines,
2. A series-parallel, ~~multi~~ two-level silicon carbide-based motor drive topology,
3. A high-power density gearbox using lightweight ~~composites~~ material
4. An integrated and actively controlled thermal management system that provides coolant directly to the motor windings and power converter,

aiming to meeting ARPA-E ASCEND targets

REEACH / ASCEND / CABLES
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Cleveland , OH

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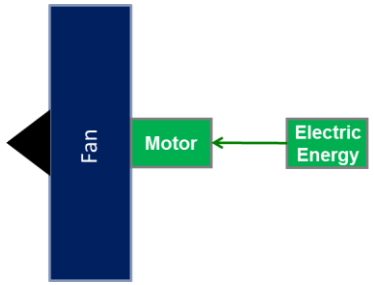
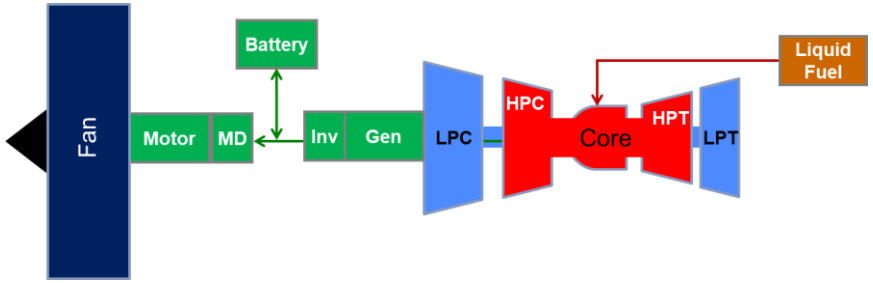
Why we care about this technology?

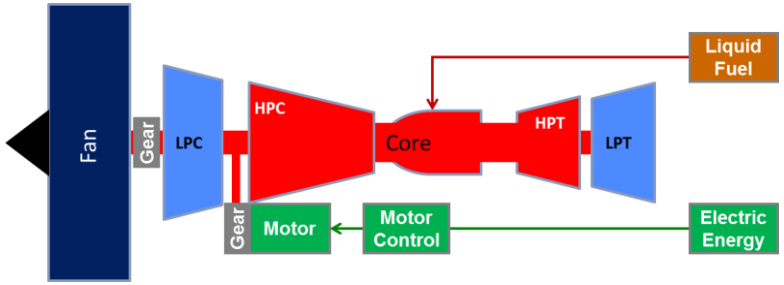
- MW scale electric propulsor: enabling advanced air mobility, creating new markets, reducing aviation's carbon footprint



250 kW



500 kW – 1 MW



1-2 MW

Photo image credit: lilium, UTAP P804 (Twitter) & Boeing

ULTRA-COMPACT Project Overview

Fed. funding:	$6.94M
Length	42 mo.

ULTRA-COMPACT Team

Team member	Location	Role in project
RTX Research Center	East Hartford, CT	Program Lead, Electric Motor, Thermal Management, Structural Design (gear box, shaft, …etc.), Integration & Validation.
Virginia Tech	Blacksburg, VT	Power Converter, Motor Drive Control, Support Integration
Purdue University	West Lafayette, IN	Thermal Management
University of Buffalo	Buffalo, NY	Advanced Insulation Material Development
AMES Lab	Ames, IA	Materials Consultant
Collins Aerospace	Rockford, IL	Design support, technology development insights, T2M

Context/history of the project

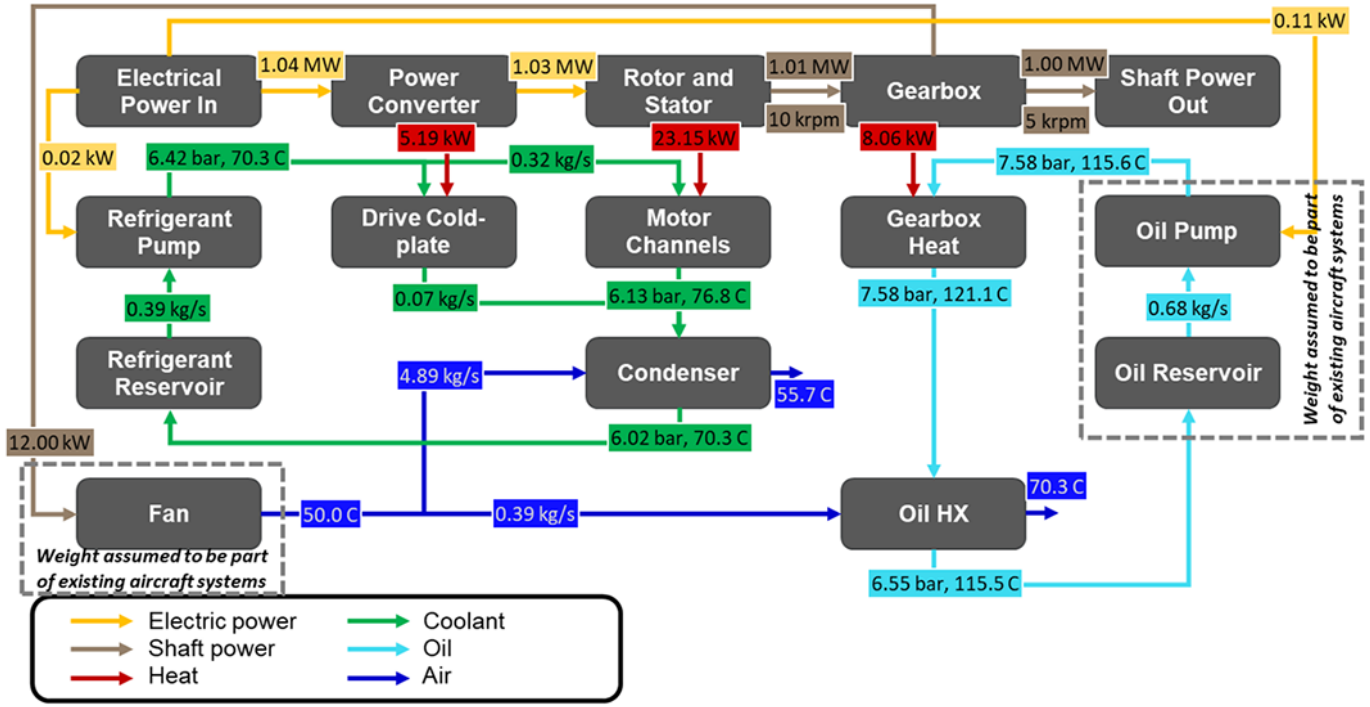
- RTRC in collaboration with its team envisions a unique approach to address challenging targets with several innovative concepts combined together
- Advanced motor topology combined with optimal power converter architecture, highly integrated gearbox and comprehensive thermal management solution
- *Success criteria:*
  - Effective risk mitigation of critical technology elements during phase-1;
  - Design, build & validate performance during phase-2;
  - Identify suitable technology transition partner and mature technology for wider adoption

ULTRA-COMPACT Key Innovations

- *Electric motor (with gearbox) key innovative features include:*
  - *Litz's wire to address the high frequency along with high strength permanent magnets*
  - *Maximize utilization of magnet to coil interaction*
  - *Highly integrated light weight gearbox*
- *Power converter key innovative features include:*
  - *Series/parallel WBG based multi-level circuit topology*
  - *Electromagnetic interleaving mode to suppress EMI emissions*
- *Thermal management system innovative features include:*
  - *A tightly integrated TMS provides custom cooling solutions to the motor, drive, and gearbox.*
  - *Heat is rejected via a ram air heat exchanger.*
  - *The full TMS is actively controlled and closely integrated in the ULTRA-COMPACT system.*

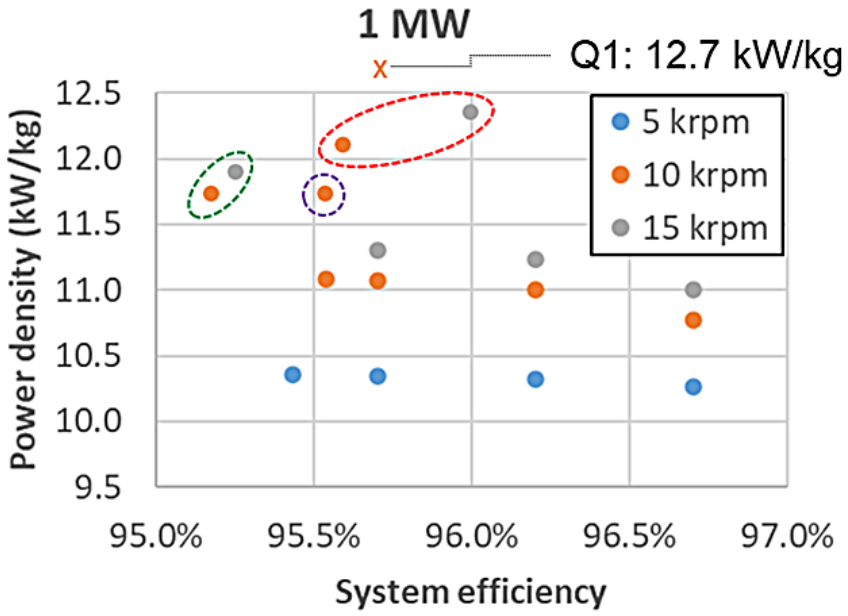
ULTRA-COMPACT System Performance

System Model



Systems end-to-end components are included in the model

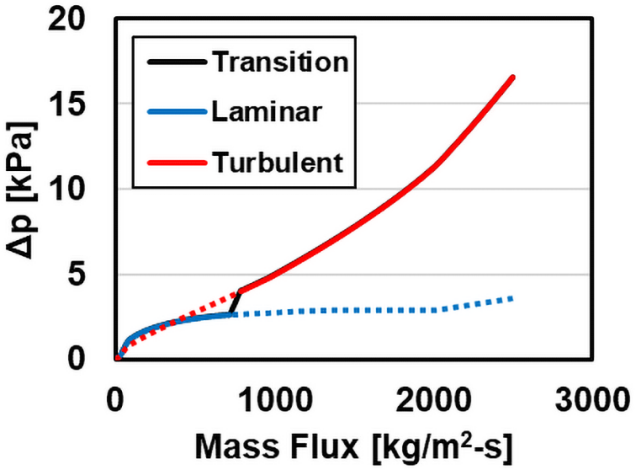
Power Density vs. Efficiency

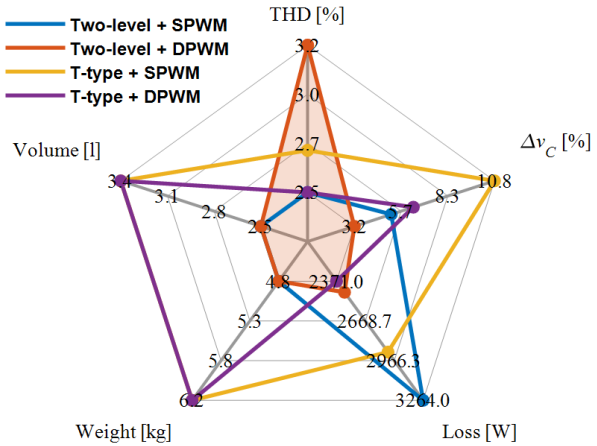


Tradeoff between power density and efficiency performed to maximize performance

System Integration and De-risking

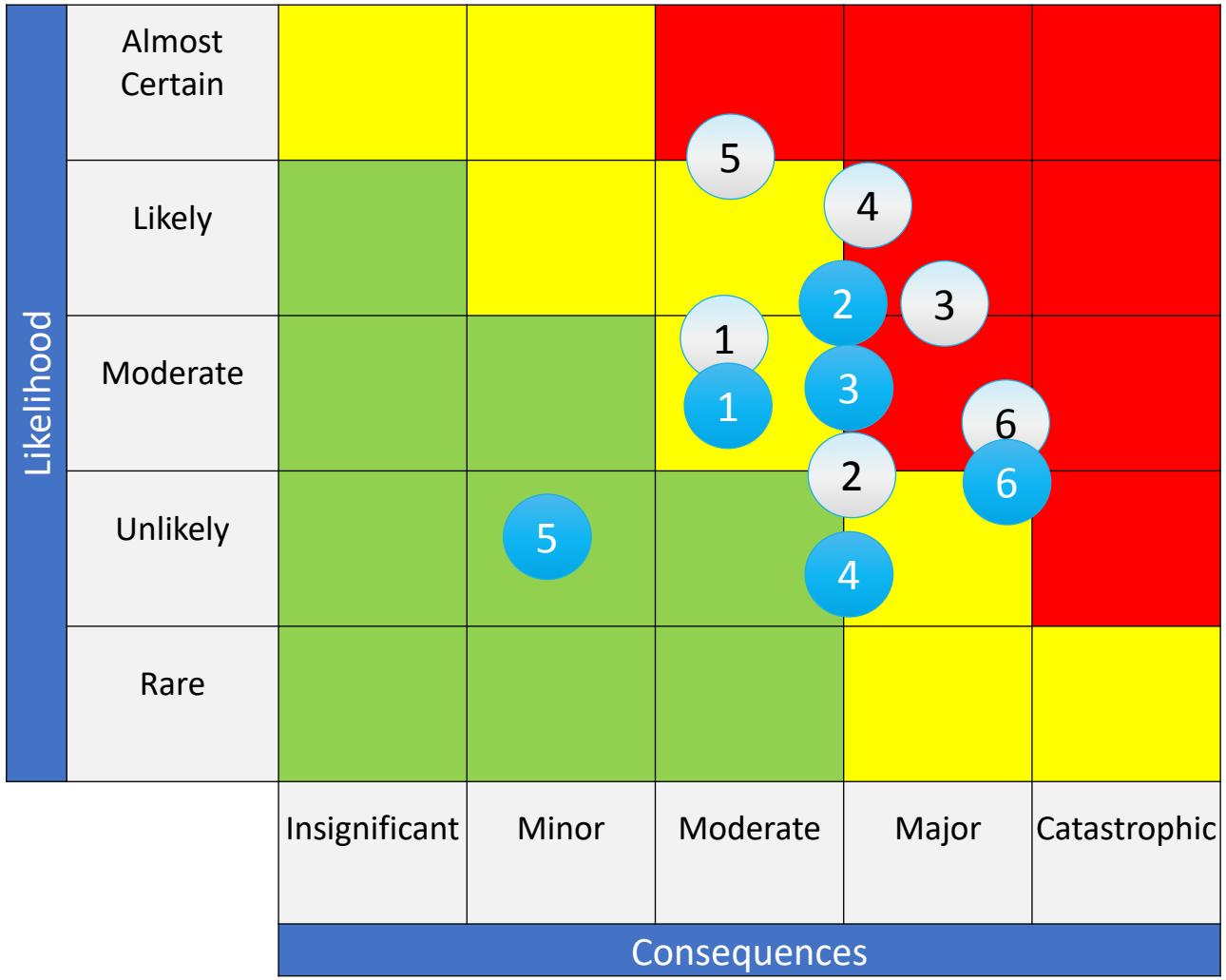
- *ULTRA-COMPACT concept was developed keeping highly integrated motor, power converter, thermal management and gearbox in mind.*
- *Considering system integration aspects early on, helped our team to leverage each sub-component vary carefully and providing dual/multi-functionality.*
- *Early de-risking of cooling channel manufacturing helped our team immensely. Further refinement might be necessary and important.*
- *High voltage, high altitude insulation design is critical to meet target metrics.*
- *Scalable ULTRA-COMPACT system architecture is best suited for various application spaces.*
- *Power converter architecture adapted to match the motor topology.*
- Effect of flow on pressure gradient and mass flux determined.





ULTRA-COMPACT Initial Risk Assessment

List the primary risks for ULTRA-COMPACT success with their respective location on risk matrix.



Risk	#
Connections (coil, drive, TMS & structural)	1
Manufacturing of magnets and rotor	2
Flow distribution from header to channels	3
High altitude high voltage electric fields	4
Gearbox material compatibility	5
Overall mechanical structure & integrity	6

Beginning of Q1 X

End of Q4 X

Raytheon Technologies

Technology-to-Market Approach

- *What's your team plan to commercialize your technology developed via the ASCEND program? What is your anticipated business model (e.g., licensing, spin-out company, internal business unit)?*
  - Collins aerospace, world leader in aviation electric system, will own the integrated system, manufacturing all components (drive, motor, gearbox) and providing the path to market. Collins current product line includes electric machines and drives up to 250 kW, this new product will extend the capability to 1 MW.
- *What are the anticipated first markets? What are the market requirements in terms of cost and performance?*
  - Advanced air mobility: 250 kW, high reliability (20,000 hr MTBF),5 kW/kg, 95% efficiency
- *What are the anticipated long-term markets? What are the market requirements in terms of cost and performance?*
  - Regional 20-50 pax series turbo-electric aircraft: 1 MW, low noise, 10 kW/kg, 95% efficiency
  - Single aisle parallel hybrid: 1 MW, 10 kW/kg, 95% efficiency

Looking Ahead – What is anticipated for an Eventual Phase II?

- *Planned risk retirement during phase-I*
  - *Rotor manufacturing with permanent magnets and retainment structure*
  - *Thermal management system flow design*
  - *High voltage, high altitude insulation*
  - *Stator integration including manufacturing tolerances*
  - *Power converter validation including EMI cancelation*
- *Planned risks to retire during the eventual Phase-II*
  - *Gearbox sub system and component verification*
  - *Delayed risks from phase-1 due to various vendor and supply chain issues*
- *T2M plan during the eventual Phase-II*
  - *Refined T2M plan with early engagement with potential early adopters*
  - *Update cost and performance model*
  - *Develop plan for next stage funding to avoid valley of death*
  - *Engage strategic partners early on*

Q & A

https://arpa-e.energy.gov